SUNLIGHT REFLECTIONS FROM A SOLAR POWER SATELLITE OR SOLARES MIRRORS SHOULD NOT HARM THE EYES

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A Solar Power Satellite (SPS) located at geosynchronous orbit (GEO) could collect sunlight above the atmosphere and return 5-10 gigawatts of electrical energy to the earth using a microwave beam from an array of klystrons arranged as a transmitter one kilometer in diameter. The transmitter must point continuously at a receiver on the earth. During some phases of the SPS orbit, the transmitter would reflect an image of the sun to the ground. It has been suggested that the reflected beam could harm an observer's eyes. It is shown here that this problem is minimal. The reflection, while bright, would not be dangerous.

In the worst case, where the transmitter is assumed to be a perfect mirror reflecting the sun's image normal to the atmosphere, the total energy received by the eye would be 3.36 x 10^{-7} watts. The eye's optics would blur the 5.6 sec of arc image of the transmitter over a disk approximately 6 minutes arc in diameter, reducing the maximum intensity at the retina by 99%. A given cone in the retina would receive even less energy due to the constant random microtremors and microsaccadic movements of the eye muscles which move the retina over an area some 8 minutes of arc in radius, even during steady fixation. Therefore, very conservative estimates made here show that the reflections from the transmitter could be viewed safely for at least 3.2 hours and that the entire SPS structure could be viewed for a minimum of 1 hour. The Solares mirror is briefly considered and is shown to be safe to view for at least 2.4 minutes.

Keywords: Power generation, alternate energy sources, solar power satellite, solares mirrors, solar energy, extraterrestrial resources, space industrialization, SPS environmental impacts, eye movements, visual perception.

An SPS at geosynchronous orbit (Figure 1) will sometimes reflect sunlight to the ground. Solares mirrors may be used to provide increased solar insolation. It was found that the reflected light from these structures would not be at dangerous levels. The subtense of an SPS transmitter array would be 5.74 sec. arc (Figure 2). Worst cases were assumed; the SPS was treated as having albedo = 1, at GEO altitude, at the zenith, reflecting light into an 8 mm pupil of a dark adapted eye (Figure 3).

The illuminace at the eye is a function of the sun's intensity, the atmosphere's transmittance and the ratio of angular area of the structure and sun, i.e.:

(Structure Area/Sun's Area)(Solar Constant)(Atmosphere Transmittance) =

$$(5.74)^2/(1.911 \times 10^3)^2 \times 1322 \text{ W/sq.M} \times .56 = 6.79 \times 10^{-3} \text{ W/sq.M}$$

The amount of energy (E) entering the pupil would be:

$$E = (4\text{mm})^2 \quad (6.79 \times 10^{-3} \text{ W/sq.M}) = 3.357 \times 10^{-7} \text{ Watts.}$$

HEW allows Class I laser doses of 0.0039 joules. It should be safe to look at the SPS transmitter image for:

$$3.9 \times 10^{-3}\ \mathrm{j}/3.357 \times 10^{-7}\ \mathrm{Watts} = 194\ \mathrm{minutes}$$

Similarly, the whole SPS structure [albedo 1.0] reflecting sunlight to the eye would have a subtense of 46 sec. arc and could be viewed for 3.01 minutes. The SPS would mostly be photo cells [albedo = 0.05] allowing exposures of 60.2 minutes. A 1 Km. Solares mirror 4000 Km. high with 51.6 sec arc. subtense could be viewed for 2.40 minutes, minimum.

Two factors reduce dose to the retina when viewing a point source. First, the eye's optics blur a point to a disk some 4 min. arc in radius, reducing peak intensity to 0.2% of the original [Figure 4, top]. Second, involuntary eye movements during fixation move the image over a retinal region some 8 min. arc in radius. The eye wanders further from the fixation point with time; so that the longer one looks, the lower the peak dose for any one area.

Figure 5 (top) shows that eye movements while fixating 1 minute wandered in an area one degree in diameter. At bottom is a magnified view of a 2 second portion of the top record, showing the eye moves in a series of small jerks, or saccades. Table 1 shows that motion reduces total dose half for 20 second exposures.

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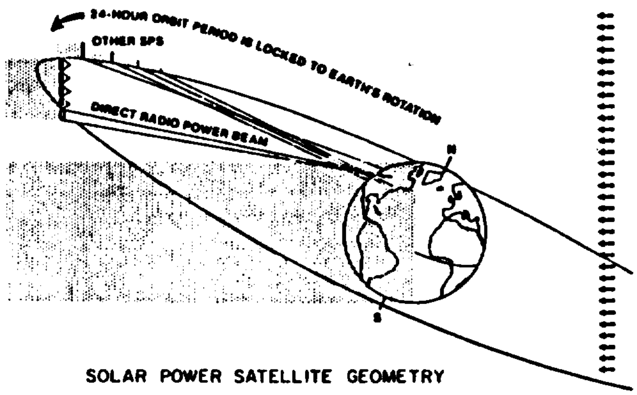


SOLAR POWER SATELLITE GEOMETRY

fig. 1

ANGULAR SUBTENSE OF SUN AND SPS TRANSMITTER

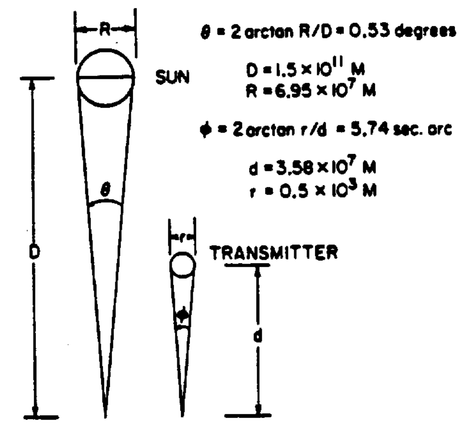
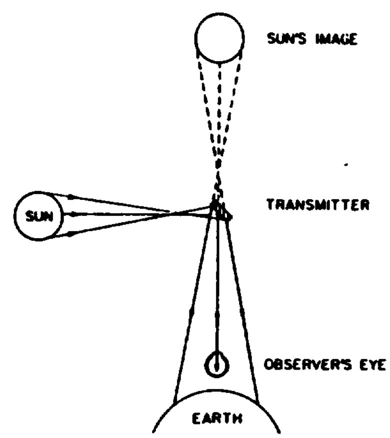


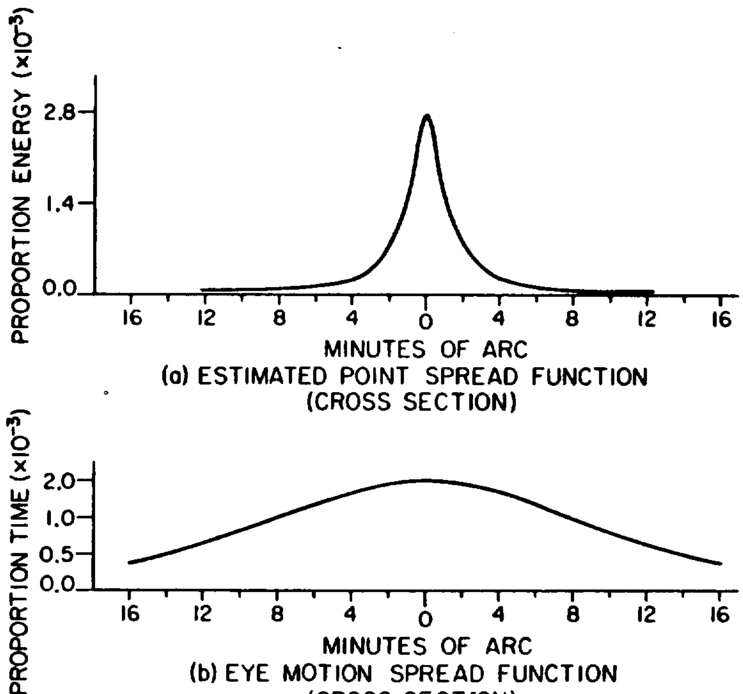
Fig. 2



RAY DIAGRAM FOR CALCULATION OF SPS BRIGHTNESS
Fig 3

TABLE 1

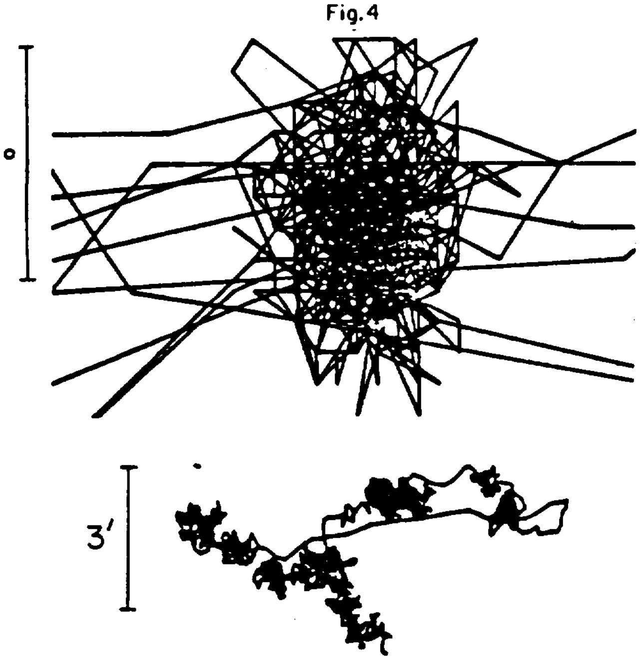
t	Prop. of Total (Moving)	Prop. of Total (Non-moving)	Moving / Non-moving	Total Joules (Moving) Watts = 3.35×10^{-7}
1	2.43×10^{-3}	2.81×10^{-3}	.86	8.15×10^{-10}
5	11.10×10^{-3}	14.06×10^{-3}	.79	3.72×10^{-9}
10	19.46×10^{-3}	28.13×10^{-3}	.69	6.52×10^{-9}
20	28.98×10^{-3}	56.25×10^{-3}	.52	9.71×10^{-9}
40	32.32×10^{-3}	112.50×10^{-3}	.29	10.8×10^{-9}
60	29.34×10^{-3}	168.80×10^{-3}	.17	9.83×10^{-9}
80	25.70×10^{-3}	225.00×10^{-3}	.11	8.61×10^{-9}
100	22.51×10^{-3}	281.30×10^{-3}	.08	7.54×10^{-9}
120	19.90×10^{-3}	337.50×10^{-3}	.06	6.67×10^{-9}



(a) ESTIMATED POINT SPREAD FUNCTION (CROSS SECTION)

(b) EYE MOTION SPREAD FUNCTION (CROSS SECTION)

Fig.4



EYE MOVEMENTS DURING FIXATION

TOP: EYE MOVEMENTS DURING FIXATION OF ONE MINUTE DURATION

BOTTOM: MAGNIFIED VIEW OF A TWO SECOND SEGMENT OF THE TOP RECORD

Fig 5